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CRES Report No. 61-9

A paper presented to the Fourth Symposium on Remote Sensing of the Environment, University of Michigan, Ann Arbor, Michigan, April 11-14, 1966.

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VEGETATION ANALYSIS WITH RADAR IMAGERY *

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ABSTRACT

Recent studies at Kansas University and by Raytheon Company have shown that vegetation analyses with radar imagery are possible within broad limits depending upon the geographic area being investigated. Imagery has been inspected for a wide range of climatic and topographic environments in the United States and in all areas influences of the vegetation upon radar returns were observable. There is sufficient information obtainable from this form of imagery to warrant its investigation both for use as a single sensor and for future use with other remote sensors.

This paper presents vegetation maps prepared from radar imagery obtained over several climatic environments. The maps and imagery have been compared with each other to determine the types of information extractable, and, where possible, conventional vegetation maps have been employed to aid in the comparison. Emphasis has been placed on the K - band and AN/APQ-56 radar systems.

Results indicate that it is normally possible, by means of tonal and textural comparisons combined with basic geographic knowledge of the study area, to: 1) prepare regional or reconnaissance vegetation maps either on the basis of physiognomy or vegetation "type"; 2) delimit vegetation zones as they vary with elevation; 3) trace burn patterns of previous forest fires; 4) delimit altitudinal timber line; and 5) identify species from inference in areas characterized by near monospecific stands. It is anticipated that radar will have a role in the preparation of physiognomic and vegetation "type" maps particularly in inaccessible or unstudied areas.

* This study was supported by the National Aeronautics and Space Administration under contract NSR 17-004-003.

I. INTRODUCTION

One of the most pressing needs in the scientific study of extensive, poorly known tracts in remote desert, mountain, tropical savannah, and arctic latitudes, is the provision of reconnaissance and semi-detailed vegetation maps. In many such areas it is still true that our understanding of the distribution of major plant communities is pieced together from a very few detailed studies in small areas. Wide areas are spliced with inferences from data of questionable reliability. In some areas indeed investigations at the turn of the century constitute the basic data source.

The aim of the present paper is to comment on some of the problems and possibilities of vegetation analysis on radar imagery for the production of reconnaissance vegetation maps to meet this need and to explore some future possibilities for quantifying vegetation analysis and for increasing our ability to distinguish between regional vegetation types.

Modern side-looking radar systems are capable of imaging up to 70,000 square miles of territory in a single day with resolutions comparable to that in the illustrations accompanying this paper. Because of its exceedingly rapid data-collection rate, large areal coverage, and small scale of presentation, radar imagery is a powerful generalizing tool for studies of natural landscape features. These advantages, allied with the virtually all-weather capability of radar make it a unique tool for rapid data acquisition in remote areas. The all weather capability is of potentially great value in areas of extensive cloud cover or haze during critical plenologic periods when discrimination of communities is likely to be easiest. In cloudy mountains, and in arctic latitudes where ubiquitous stratiform cloud-decks impede summer-time photography and in tropical regions where various mixes of cumuliform and stratiform clouds, moisture haze and so on occur, radar's all-weather ability is a matter of some importance.

A number of studies have indicated the value of radar in reconnaissance and regional geologic mapping (Cameron 1965, Beatty et al 1965, Pierson, Scheps and Simonett, 1965). However, little has been done with vegetation and we hope that this paper will interest plant ecologists and plant geographers to explore the potential of radar for vegetation studies.

This study is sponsored by the National Aeronautics and Space Administration (contract NSR 17-004-003) with a view to evaluating the utility of radar as a tool for geoscience research on orbiting spacecraft.

2. LITERATURE SURVEY

To our knowledge the only unclassified studies of vegetation analysis with radar imagery are those by Beatty et al (1965) and Simonett and Morain (1965). Both of these studies were made with single frequency "brute force" mono-polarization radars used monoscopically. The radars were the K_a band AN/APQ-56 system and the X-band AN/APQ-69 system. Non-imaging radar studies of vegetation employing a scatterometer for measuring radar backscatter per unit area as a function of viewing angle (σ_o vs θ) are those by Reitz, E.A. (1959) Cosgriff, Peake and Taylor (1960), and Moore, Janza and Warner (1959). In addition to being studies with a non-imaging device, these radar reflection studies have concerned themselves mostly with reflections from small areas in fields rather than from natural vegetation (Cosgriff, Peake and Taylor 1960), from very broad categories of natural vegetation (Moore, Janza and Warner, 1959), or with a mixture of cultivated and natural vegetation (Reitz, E.A., et. al., 1959).

The study reported on here is an attempt to carry some of the ideas and conclusions in these five papers a little further, particularly in regard to the sensing of natural vegetation. A companion study dealing with cultivated crops is also underway at the University of Kansas in conjunction with Dr. Andrew Erhart of the Garden City Agricultural Experiment Station in western Kansas.

3. METHODS FOR THE ANALYSIS OF VEGETATION WITH RADAR IMAGERY

In the discrimination of plant communities on radar imagery there are a number of methods which aid separation: 1) differences in average gray scale values between communities, 2) probability density functions per unit area derived from film both for area-extensive discrete objects and for aggregates of objects, 3) discrimination of textural differences, 4) edge effects, especially those which arise from different means of gradation from one plant community to another in nature, and which may be handled through analysis of acutance on the image, 5) analysis of spatial arrangements, based on a knowledge of the general distribution of plant communities in an area, 6) evaluating the context of associated objects, both internal to a single community and external forms, 7) image transformations via optical means, including the one and two-dimensional Fourier transform, 8) differentiation, 9) integration, 10) expansion of portions of the dynamic range, and 11) level slicing. Items 8 through 11 also lend themselves to two-dimensional multi-color presentations involving use of the luminance and two chrominance channels in a color television system, and photographic color methods. These do not exhaust the possibilities.

All the above are concerned with single images. However, simultaneously recorded imagery giving the full polarization matrix and/or two or more frequencies is now becoming available and data of this type is potentially suitable for certain additional types of analysis including: 1) polychromatic display techniques involving television and multiple flying spot scanners and photographic color methods, and 2) derivation of sums of differences of signals in both one-dimensional and two-dimensional form.

Finally, there is the possibility of using time as a discriminant tool to improve identification through variations in all the above types of data at different stages of the growth cycle of plant communities.

4. SOME METHODS USED IN THIS STUDY FOR ANALYSIS OF VEGETATION

It is intended that experiments in the above forms of image processing and analysis be made at the University of Kansas for the study of vegetation. We are however still in the early stages of evaluation and only a few of these possible techniques were used in this paper.

Three of these techniques will be unfamiliar to most ecologists and plant geographers, so that it is appropriate to briefly review them here. They are: 1) use of simultaneously obtained multiple polarization radar images, 2) radar image texture variations and 3) probability density functions of each plant (structural) community.

4.1 MULTIPLE POLARIZATION RADAR IMAGES

In studying the effect of polarization of radar return signals from vegetation, two cases must be considered: first, the radar return as a function of the polarity of the transmitted signal alone, and second, the radar return as a function both of the polarity of the transmitted signal and the depolarizing properties of the terrain. These two phenomena may be conveniently separated by the use of radar imaging systems which record the full polarization matrix and, when transmitting signals of one linear polarization, receive signals with both direct and orthogonal polarizations. A number of such systems are in operation and images are being studied for polarization interaction with natural and cultivated vegetation.

The first case applies when terrain depolarization of the back-scattered signal is slight and where the return signal is high for one linear polarization and low for another. This situation thus applies when the horizontally polarized signal both transmitted and received (which we may designate HH), is compared to the vertically polarized signal transmitted and received (VV).

The second case applies when terrain depolarization of a transmitted signal is sufficient for recording on film. Analysis may then be made of the relative depolarization produced by different vegetation types, by comparing the VV or HH image with the appropriate cross polarized image (horizontally transmitted, vertically received, designated as HV; and the equivalent for vertical transmission, designated VH). In this paper all the comparisons available are of the second type between HH and HV images only.

The cross polarized return is normally down about 10 db from the like signal and the gain on the cross channel receiver may be adjusted to give like and cross images (HH and HV) of comparable gray scale intensity. Since the system is not calibrated the images cannot be used quantitatively, but they are appropriate for qualitative comparisons of differences.

4.2 IMAGE TEXTURE ANALYSIS

Variations in image texture are also significant in helping to discriminate between classes of natural vegetation. Beatty et al (1965) have studied such texture variations as are shown on the AN/APQ-56 imaging radar, (a K_a-band "brute force," side looking system) in the Front Range and High Plains of Colorado and other areas and concluded that a judicious but rather limited use of textural differences would help in regional vegetation mapping with the AN/APQ-56 radar.

The "texture" apparent on a radar image of vegetated areas is composed of two separate components, namely a system component and a true vegetation component. The system component arises from the number of pulses averaged per resolution element. This may range from a few to several hundred, depending on the system. The more pulses averaged, the greater the probability of achieving a relatively uniform gray scale for a given essentially homogeneous area. However when very few pulses are averaged, as in the case in much synthetic aperture radar imaging, the wider is the spread of gray scale values per unit resolution cell and the "grainier" the image appears on an enlargement.

All radar systems have some residual system texture as described above and this is true even over near-specular reflectors. This residual or inherent texture arises from variations in the average return per unit resolution cell, over essentially homogeneous terrain in which roughness is measured on a micro scale.

Textures coarser than this residual or system component may reasonably be expected to reflect in part real differences in meso and macro terrain roughness characteristics (including shadowing) to which the radar is sensitive.

Even casual inspection of radar imagery suggests that a three or five category texture classification (for a given radar system) from "very fine" to "very coarse" could be used with comparative reference masks. However each system differs from all others as a function of the radar wavelength, ground resolution, and viewing angle used. For our purposes here we have followed a semiquantitative 5-category texture range. A considerable amount of additional work is necessary to evaluate and derive quantitative measures of texture. It is our intention to continue a study of texture variations with different frequencies and systems, and it is our understanding that Beatty and others in Autometrics Corporation are also working in this area.

4.3 PROBABILITY DENSITY FUNCTIONS OF VEGETATION TYPES

Probability density functions derived from radar imagery represent the third method used in this study which has potentially wide application in the study of vegetation. These functions were developed by scanning 5X film positive enlargements of HH and HV images. The ground area scanned was roughly .75 to Km^2 or about 1 square inch on film. The flying spot scanner used was coupled to a pulse height analyzer. Scanning was at the rate of 7,000 pulses per second for 10 seconds in all cases, so the peak amplitudes are comparable. The X axis is a plot of intensity, derived by measuring film transmittance (radar return energy increases left to right on the illustrations), and the Y axis gives the frequency of occurrence of given film transmittances (or return energies). We employed 175 channels to encompass the full dynamic range on the radar image film.

The curves produced with this system define the probability distribution (and hence the variances) of given energy levels for apparently uniform classes of natural terrain -- in this case structural vegetation types. Many of the curves are essentially gaussian and range from narrow to broad. Some are decidedly skewed, some are bimodal, others seem almost to follow a Raleigh distribution function. Finally the average gray scale values differ somewhat between vegetation types. Potentially, therefore, the curves would appear to lend themselves to both quantitative and nominative classification as another means of discrimination between vegetation classes.

The curves illustrated later in this paper suggest to us that certain distinctive vegetation mosaics or types in tropical savannahs, savannah woodlands, thorn woodlands etc. may have relatively unique bimodal or even trimodal probability density distributions, arising from the spatial distribution of the various life forms in the community. When radar imagery is obtained of such tropical areas it will be appropriate to test this hypothesis. It will be recognized also that the probability density function for vegetation communities is itself conditioned by the resolution, frequency and type (real aperture or synthetic aperture) of the radar system employed and the naturally-occuring distributions of major and minor reflecting elements in the landscape. Even modest resolutions are likely to be of considerable value because many of the natural spatial periodicities to be sampled (detected) are larger than the resolution net being used. However, high resolution radar systems promise to give considerably more data on communities with fine spatial periodicities, and will need to be studied in detail. To what extent there are families of probability density functions for a given vegetation type (related to differences in radar resolutions) and where the critical resolution limits lie are all matters for future investigation.

5. SOME ANALYSES OF RADAR IMAGERY

Examples illustrating the potential use of radar imagery for interpreting vegetation patterns and conditions are presented for three areas representative of relatively poorly known arid, mountain and arctic environments. These are in the semi arid zone of southwestern Utah, the relatively densely vegetated mountains of central Oregon and the permafrost zone of interior Alaska. From these illustrations we hope to highlight some of the present means of extracting vegetation information from imagery.

Escalante Valley, Utah lies in the semi-arid Great Basin and is dominated by large tracts of uniformly low, and often sparse, shrubby vegetation. This area was selected for study because recently acquired K - band imagery for a number of basins in the semi-arid west show similar patterns of radar return which are of possible vegetation origin. Reconnaissance field investigations have been carried out in this area and comparison of radar imagery with actual vegetation conditions confirms the influence of vegetation on radar returns.

Horsefly Mountain, east of Klamath Falls, Oregon, lies in the transition region between Great Basin vegetation similar to that in Escalante Valley and more mesic conifer forests of the Pacific Coast. The great contrast in physiognomy between vegetation types in this area makes it useful for evaluating image texture patterns for different stages of forest growth. Field studies are planned for this site from which we hope to extend our interpretations of image texture to other areas.

Yukon Flats, Alaska is included as an example of the potential of radar in vegetation analysis because studies have already shown the ability of radar to detect burn patterns in areas burned as long ago as about 1940. Fire is recognized as one of the all important influences on vegetation patterns in numerous environments ranging from the tropics to the high latitudes; thus the use of radar as a remote sensor of this phenomenon may help to solve many unanswered questions regarding the rate and possibly the direction of succession after fire, aside from being of more immediate practical utility for foresters interested in forest regrowth.

5.1 ESCALANTE VALLEY, UTAH

Escalante Valley in southwestern Utah is flanked by the rugged Mineral Mountains on the east and the Star Range on the west. Coarse textured pebbly alluvial fans issue from the canyons of these mountains and grade gradually into finer textured soils toward the floor of the valley near Milford. In general, vegetation types are closely tied to conditions of soil texture, salinity, and depth, in such a manner that distinct elevational zones may be recognized.

Sagebrush (Artemisia tridentata) occurs in nearly monospecific zones on alluvial fans. Locally it may contain patches of little rabbit brush (Crysothamnus lanata), but generally the sagebrush zone has been largely stripped of other species by grazing. A zone of shadscale shrub (Artiplex confertifolia) becomes dominant on the finer textured soils in the lower parts of the valley, and there is often a very narrow transition zone between these two types. In the lowest, and often saltiest areas, shrub species may disappear altogether in favor of saltgrass and pickleweed. In addition to the species mentioned there are only a few other important woody or herbaceous shrubs characteristic of Escalante Valley, and none of these occupy recognizable zones.

Even though species are segregated into zones, vegetation throughout is quite uniform in height (< 1 m) and species tend to be quite similar in geometry. Shrubs are small and intricately branched, with small leaves ranging in size from a few mm to one or two cm. Shrubs tend to be round with the main branches more or less erect. They are irregularly deciduous and widely spaced, rarely forming stands of greater than 60% cover. Dead bushes, of which there are many, often remain intact, and are sometimes difficult to distinguish from live bushes in a deciduous phase.

Radar imagery of the Milford area (fig. 1) was obtained October 19, 1965 with a multi-polarization radar system. Weather conditions for the week immediately prior to the overflight were near normal with an average daytime temperature of ca. 19° C and a total of .75 mm precipitation. There was, however, no precipitation for three days prior to the flight (Climatological Data, Utah, Oct. 1965, Vol. 67 # 10).

A tentative vegetation map (fig. 2A) was prepared from inspection of both the HH and HV polarized images of Escalante Valley. At the time this map was prepared it was not known definitely whether radar returns represented vegetation patterns, surface material patterns, or salt patterns; consequently, it illustrates film density categories to which probable vegetation types were assigned that are consistent with known Basin and Range vegetation. In an effort to trace on the ground the density categories extracted from the imagery, a field check was conducted in late January and early February, 1966. A second map (fig. 2B) shows the results of this investigation.

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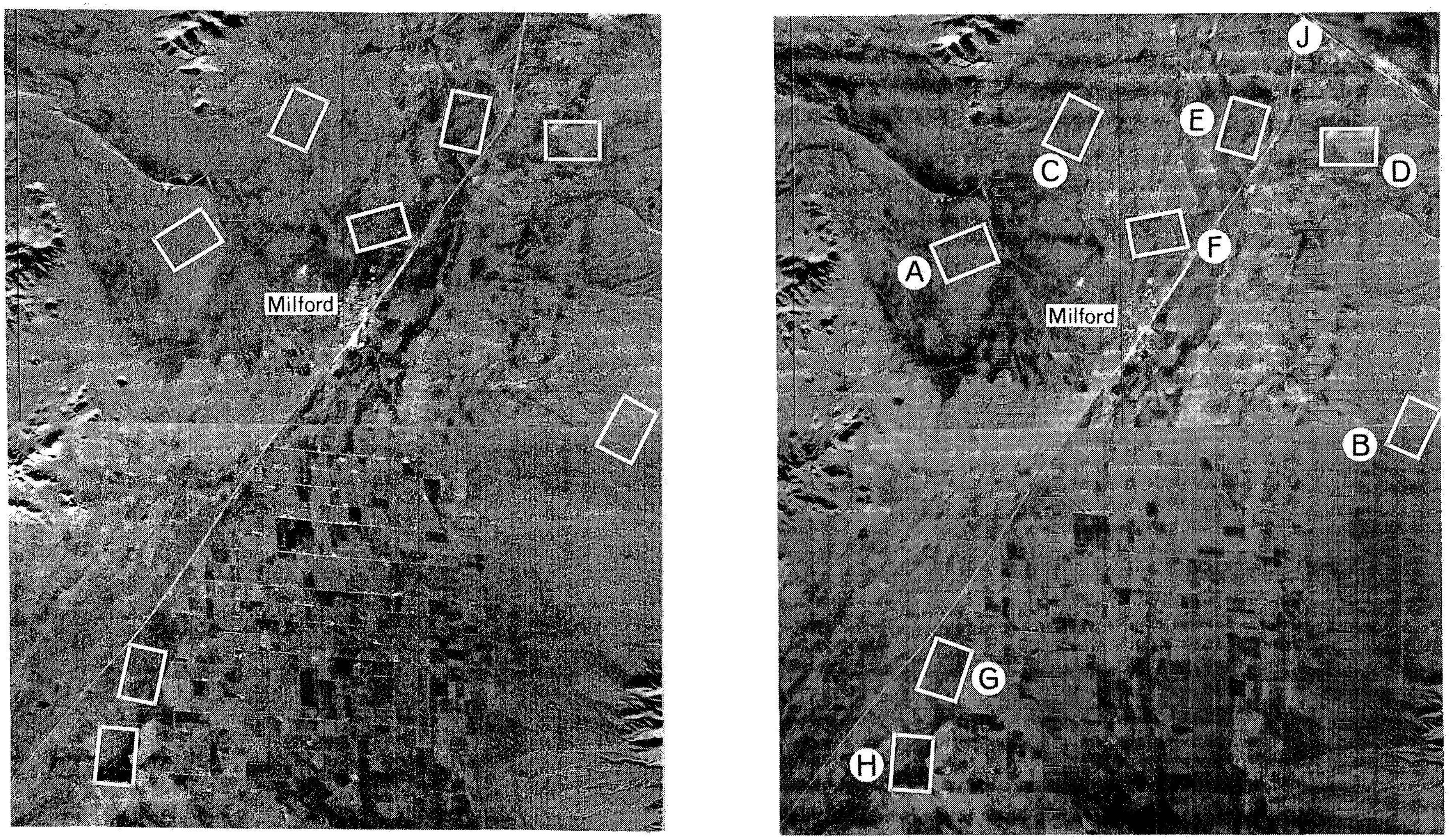
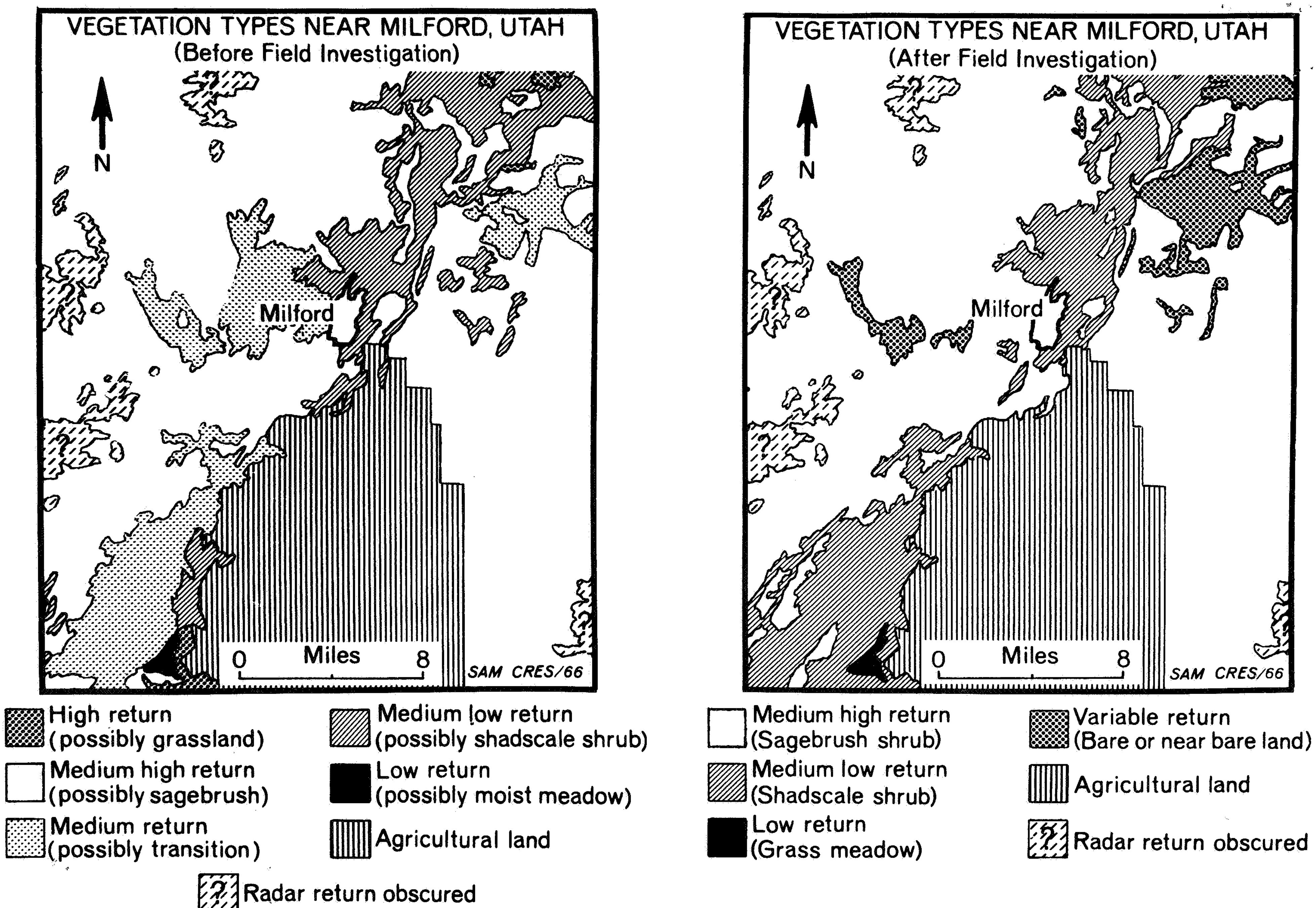


(A)
HH polarization

(B)
HV polarization

K-Band Radar positive imagery of portion of Escalante Valley, Utah

Figure 1



(A) (B)

Figure 2 Vegetation maps derived from K-Band radar imagery for the vicinity of Milford, Utah

Fig. 2A and 2B are generally comparable except for the category originally interpreted as shrub transition in the laboratory analysis. The absence of this category in the field points up the fact that vegetation zones in this environment lack broad transitions, and suggests that somewhat more latitude in film density categories must be allowed in order to accurately delimit zones. The same may be said for areas which are bare or nearly bare of vegetation. These may yield a range of film densities which are related to variations in surface material roughness or moisture content. Thus they may appear on the imagery as either areas of high or low energy return.

Results of the field investigation are outlined below which are of importance for interpreting the imagery.

1) Radar return patterns in Escalante Valley correspond primarily with vegetation patterns, but, since the individual shrubs are widely spaced, the range of film densities depends also on the roughness of surface alluvial material. On the higher portions of the alluvial fans, surface materials are gravelly and rough in relation to the wavelength, resulting in increased scattering of radar signals and a higher proportion of return (light tones on a film positive). However, toward the center of the valley the surface material becomes finer and the moisture content probably increases. Both of these conditions would tend to diminish return signals. In the sparsely grassed areas on the gravel fans northeast of Milford (see area J on fig. 1B) returns are extremely high. Immediately south of area J, sagebrush covers enough ground that radar returns are lowered in comparison to the adjacent gravel surface.

2) Sharp boundaries in film density are judged to be due largely to vegetation changes, since the mean size of surface material particles decreases in a gradual manner from gravel a few centimeters in diameter on the upper fans to clay loam and clay soils near the center of the valley. Minor variations in film density are attributed to local changes in shrub density. Figure 3A shows a relatively clear area in the sagebrush zone on the west side of Milford. On the imagery this area (fig. 1B-A) has slightly lower film density (lighter gray) than the surrounding denser sagebrush type (darker gray). Studies in western Kansas agricultural lands have repeatedly demonstrated the same phenomenon: the radar return is markedly influenced by the density or percentage of ground cover by vegetation. In reconnaissance type mapping it is not always practical to delimit these minor occurrences. Indeed, doing so could be misleading because not all areas of similar film density would necessarily be equivalent vegetationally or texturally. Moreover, a strictly laboratory interpretation would give no basis for such a fine distinction. Fig. 3B was taken near site E on fig. 1, and illustrates a more typical aspect of the sagebrush zone near Milford.

3) Vegetation height seems to be of secondary importance in influencing radar returns because of the overriding influences of shrub density and the coarsness of surface gravels. Where variations in height are accompanied by changes in life form, however, as in the grass meadow at site H, there may be significant influence on the return signal. More studies are needed to evaluate the relationship between shrub height and density in semi-arid environments, as the results may be equally applicable in other areas of predominantly shrub vegetation, viz a viz arctic and alpine tundras.

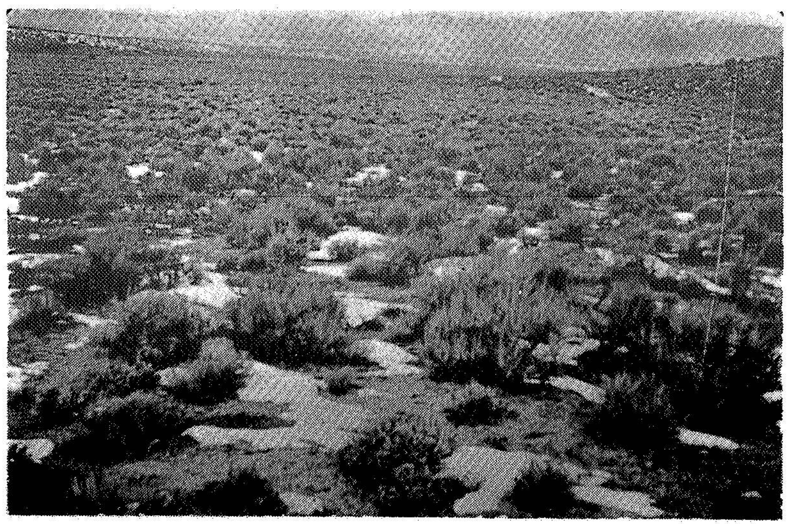
4) As is evident from the imagery, the absence of distinct variations in image texture makes separation of vegetation zones difficult. Visual interpretation rests solely on film density patterns, which may vary considerably for some vegetation types depending upon the nature of the underlying surface material. Development of techniques for statistically analyzing images may improve our "eyesight" immeasurably and eventually permit us to separate less distinct vegetation types.

5) Comparison of radar imagery with conventional panchromatic aerial photography reduced to an equivalent scale (fig. 4) demonstrates one of the chief advantages of radar as a remote sensor of vegetation; that is, the ability of radar to generalize over large areas and reduce unnecessary detail. While detail is abundant on aerial photography, there is little evidence of vegetation zonation.

Probability density curves are illustrated for several vegetation types in Escalante Valley (fig. 5). These curves were generated by scanning areas 1" x 3/4" on 5X enlargements of HH and HV positive transparencies (ground dimension approximately .8 x 1.2 km). With the exception of areas D and H (see fig. 1) all areas had more or less uniform film densities. Nevertheless, the presence of several peaks on most of the curves suggest that the areas have non-homogeneous surfaces.

Curves for areas A, B, and C represent sagebrush with almost no grass understory on a pebble surface. Each curve has a broad peak in the medium intensity region flanked by a narrower and lower bimodal region of lower intensity to the left. Area D, which represents bare land with several pockets of sagebrush has a similar appearance, but the curve for the HV image in particular

(A) Aspect of sagebrush at area (A) Escalante Valley, Utah Feb. 1966

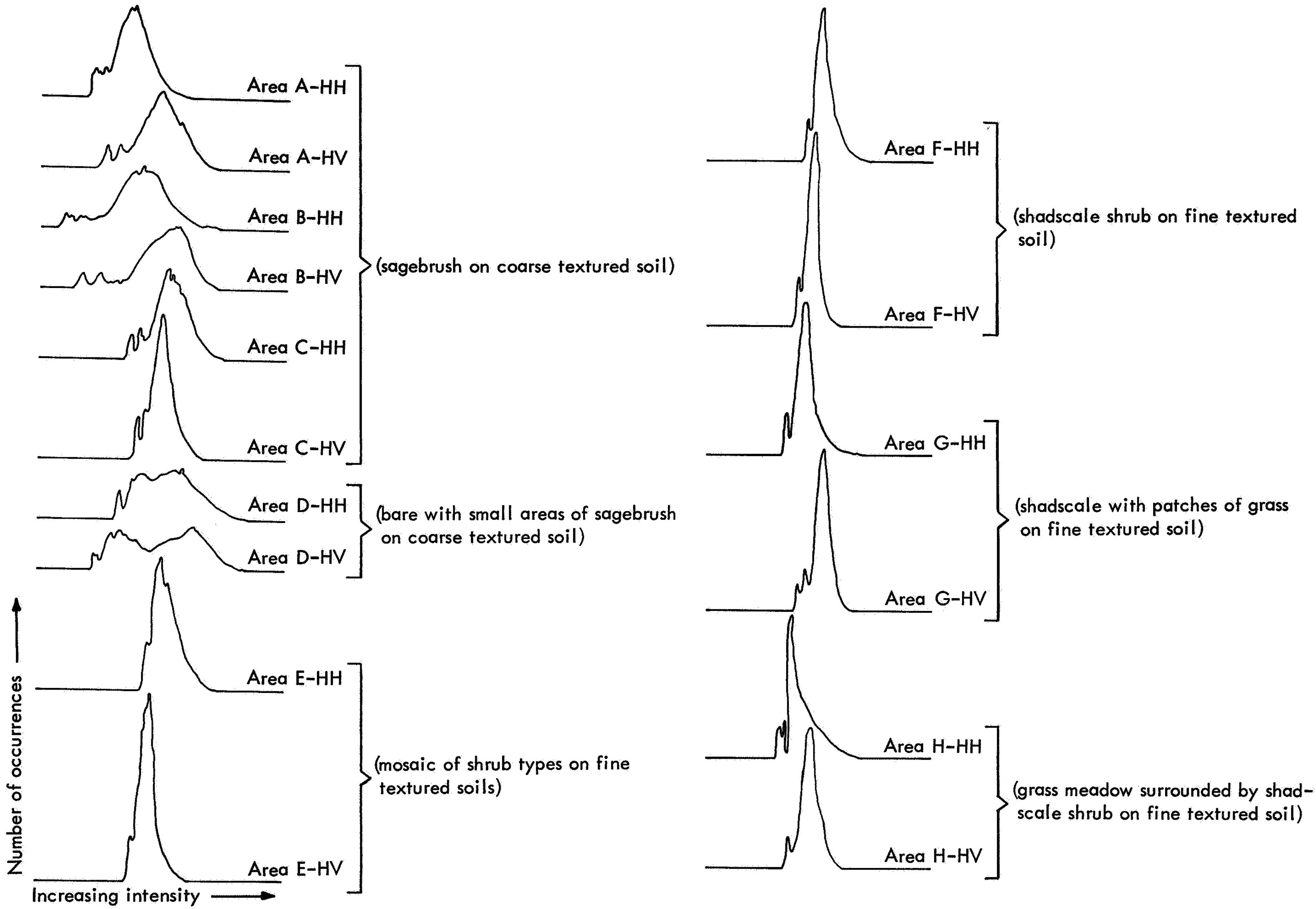


(B) Typical aspect of sagebrush throughout most of Escalante Valley, Utah Feb. 1966

Figure 3

Airphoto mosaic of portion of Escalante Valley, Utah reduced to scale of radar imagery

Figure 4



Probability density curves for representative vegetation types (film densities) in Escalante Valley, Utah

Figure 5

shows an increase in breadth and height for the middle peak and a decrease in height for the right hand peak. If we assume that each peak represents a different phenomenon on the ground, the middle peak may represent the return energy from bare ground. The small, low intensity peak on the left may represent return energy from features such as drainage ways or minor slope variations. All of these assumptions bear the burden of proof, however, and this can be gained only through intensive field work in small areas.

Areas E, F, and G lie largely in the vegetation zone dominated by shadscale and fine textured soils. Area E however consists of a compact mosaic of other species such as greasewood and little rabbit brush, and area G contains patches of saltgrass. All of these curves have a single sharp peak in the medium intensity region with one or two small appendage peaks on the left flank. Minor variations in the shapes of the curves are observable which further study may show relate to differences in terrain processes.

In a properly calibrated imaging system (the radar system used was not calibrated) it should be possible to combine (subtract or add) information contained in the HH and HV curves and to correct for differences in db between them, giving a resultant curve which could be read, for example, to test whether the shadscale-greasewood-little rabbit brush mosaic of area E could be distinguished from the purely shadscale type of area F.

Curves for area H are puzzling because they do not agree with the visual impression of film density variations within the outlined area. One would expect a single peak in the low intensity region, one in the medium to high intensity region, and a broad curve connecting these two throughout the middle intensity region. Consequently, the occurrence of a curve similar to those for shadscale types is surprising and we intend to pursue this problem further.

In summary, radar imagery, combined with analytical interpretation techniques, may serve as a reliable tool for intermediate scale mapping of already recognized vegetation zones in the semi-arid part of the United States, and may thus be of significant value for ecologists, botanists, and range managers interested in knowing actual distributions of grassland, shrub land and grazing density of stands. Because the vegetation is uniform, however, there is relatively little opportunity for utilizing "edge effects" and image texture patterns as interpretation aids. Physiognomically diverse areas such as that illustrated for south-central Oregon, which we may now study, are most amenable to utilizing these techniques.

5.2 HORSEFLY MOUNTAIN, SOUTH-CENTRAL OREGON

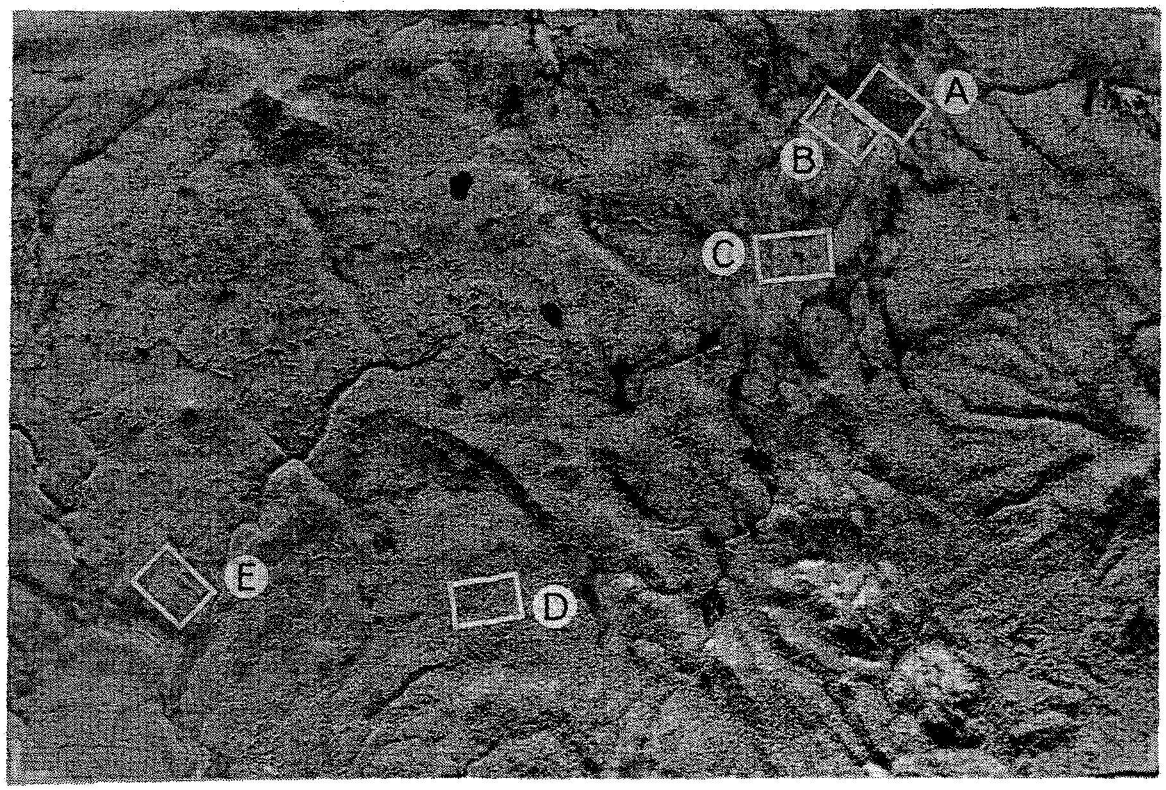
Figure 6 illustrates K - band HH and HV polarized images obtained in October, 1965 for the vicinity of Horsefly Mountain in south-central Oregon. This region is characterized by a coarse mosaic of pine forest with low lying shrub and grassland (Andrews and Cowlin, 1936; Küchler, 1964). Figure 7 is a reproduction of Bly Quadrangle (USGS 1:62,500) showing the gross distribution of forest and non-forest areas, and figure 8 represents a tentative vegetation-type map prepared from the radar imagery. Enlargements of the major image textures, which served as the basis for segregating types, are illustrated in figure 9, while probability density curves for five selected areas within some of these texture categories are presented in figure 10. Figure 8 has not yet been field checked for accurate identification of types because heavy snow blanketed the area just as we were to begin field work. However, there is little doubt that the distribution of at least the forest and non-forest areas is quite accurate if correction is made for system geometry. The area will be studied in the summer of 1966.

Details of forest distribution on the HV image compare favorably with shaded areas on the topographic map, while regions of low energy return (dark gray on the film positives) on the HH image correlate remarkably well with those designated as marsh lands. Areas denoted as shrub on the topographic map (stippled pattern) have a variety of textures on the imagery, and some regions which are designated as forest on the topographic map appear to fall more into the class of low forest or shrub on the imagery, as does that below and to the left of site E. Grassland areas also vary in representation on the imagery, in some instances occuring as high energy returns and in others as areas of moderate return.

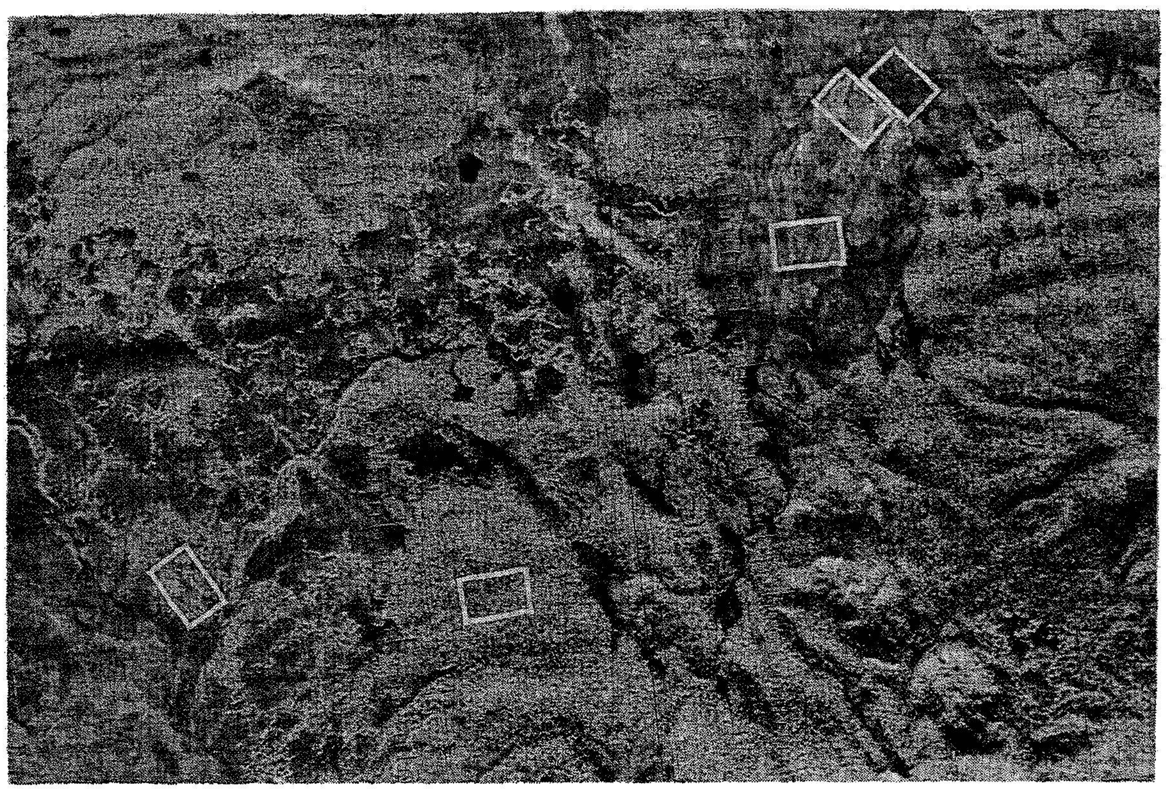
Attention should be drawn to obvious imagery differences between the HH and HV images. In comparing the two polarizations it is clear that the forest/non-forest boundaries and areas are enhanced on HV imagery through emphasis of image textures, increased contrast, and sharpened acutance angles. Since these distinctions are not as clearly observable on imagery of areas which are apparently similar in vegetation, some questions regarding the causes for these are warranted.

Published accounts of vegetation types in south-central Oregon indicate the dominance of needleleaf evergreen forest in the higher elevations; relatively broadleaf evergreen chaparral on

Figure 6

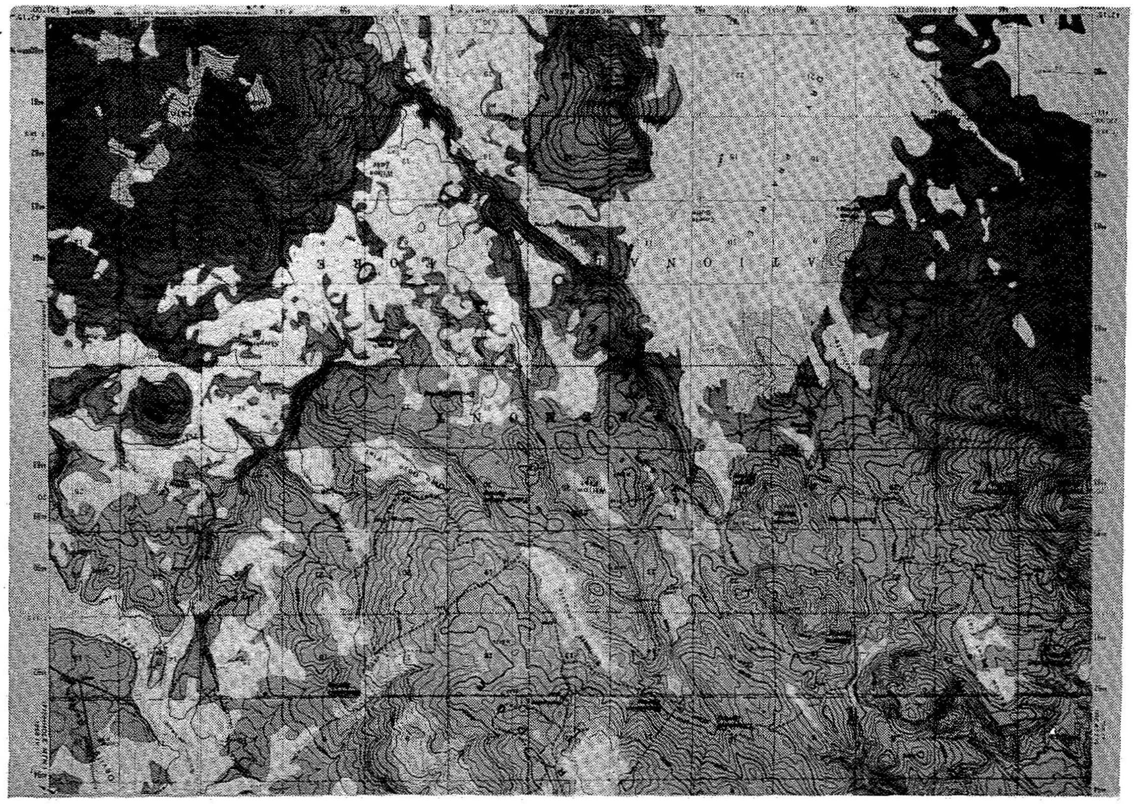


(A) HH polarization



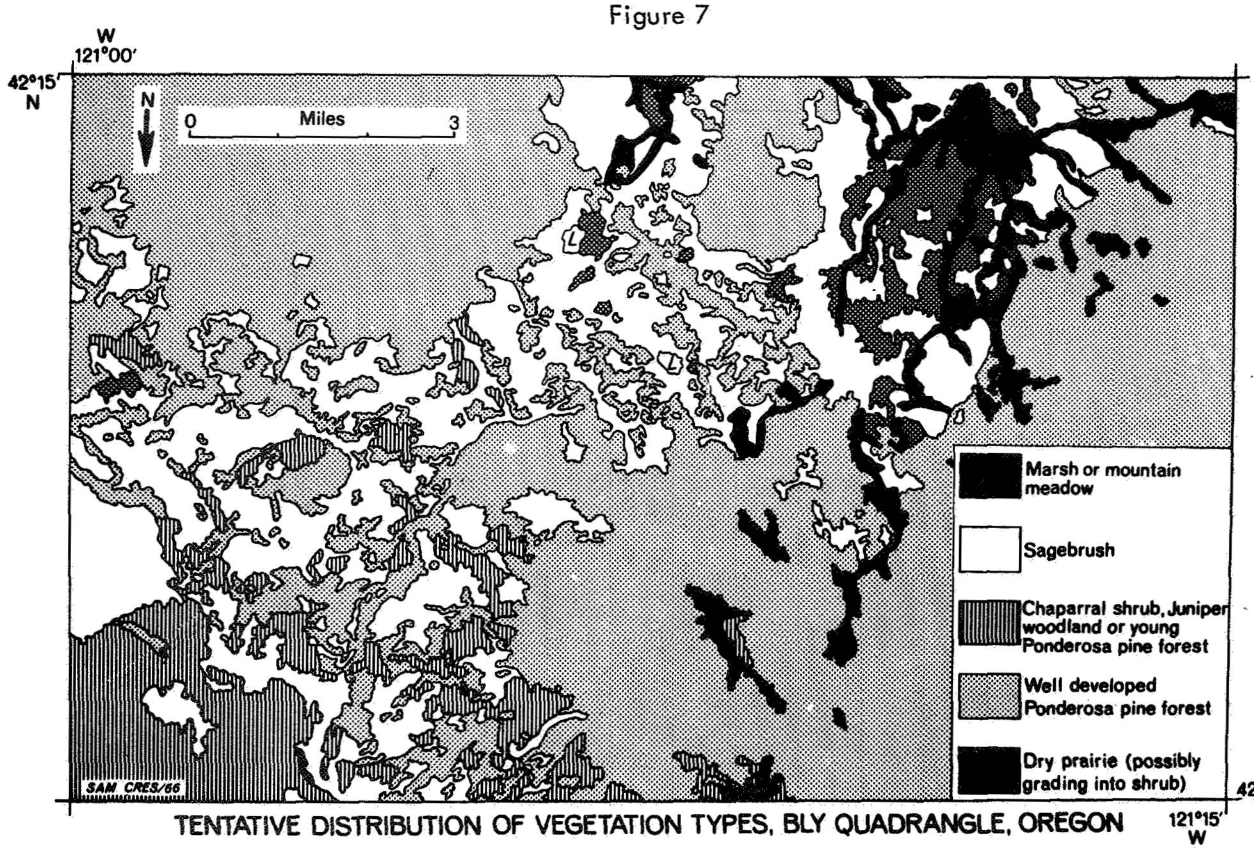
(B) HV polarization

K-Band Radar positive imagery for the vicinity of Horsefly Mtn., south-central Oregon. Areas A through E represent the major film density and image texture classes which were utilized in preparing a tentative vegetation map for this area.



South half of Bly Quadrangle (USGS 1:62,500). North has been inverted 180 degrees to avoid inverting topography on the corresponding radar imagery.

Figure 7



Distribution of vegetation types, Bly Quadrangle, Oregon. Compiled from laboratory analysis of K-Band radar imagery on the basis of film densities and image textures. Type descriptions are inferred from Andrews and Cowlin, 1936, and Kuchler, 1964.

Figure 8

burned and cleared slopes; broadleaf microphyll shrub on lower lying level areas; and grassland in mountain meadows and along the flood plains of larger streams. Differences in macro and micro roughness together with differences in dielectric properties between these major types may in part explain their differing abilities to depolarize radar signals.

Inspection of the HV polarization (fig. 6B) shows that the returns from sagebrush are notably lower than in the HH image (fig. 6A). Because of this the relative contrast between sagebrush and adjacent coniferous forest and grassland is magnified in the HV image. We suspect that leaf orientation and leaf length in both conifer and grassland make these targets rougher on a micro scale than the sagebrush, and hence the latter depolarizes the transmitted signal to a lesser extent. Of course differences in dielectric properties between these vegetation types may also contribute to the observed differences.

The overall appearance of the two radar images suggests that reconnaissance vegetation maps of scales ranging between 1:100,000 and 1:62,500 could be prepared by utilizing the visual aspects of film density and image texture. More sophisticated interpretation techniques combined with data collected simultaneously from other sensors may further enable more precise separations by type of vegetation.

The enlargements of image texture in figure 9 can be grouped into forest and non-forest categories. This distinction is readily apparent on the basis of coarseness and contrast between points of high, medium and low energy return. The texture for well developed forest (D) has a wide spread of values from high through medium to low intensities, and also a notably coarse texture. Trees in this category have been described as conifers 150 to 200 feet high covering more than 80% of the ground (Andrews and Cowlin, 1936). Although it has not been confirmed from field studies, it is possible that the observed coarse image texture and marked variations in signal level result from a high gross roughness envelope and many large reflectors such as tree trunks in the forest combined with areas of no or little return arising from partial shadowing. The coarseness of the pattern and the relatively small proportion of medium intensity suggests that returns are coming from groups of trees and that little of the transmitted signal is reaching ground level.

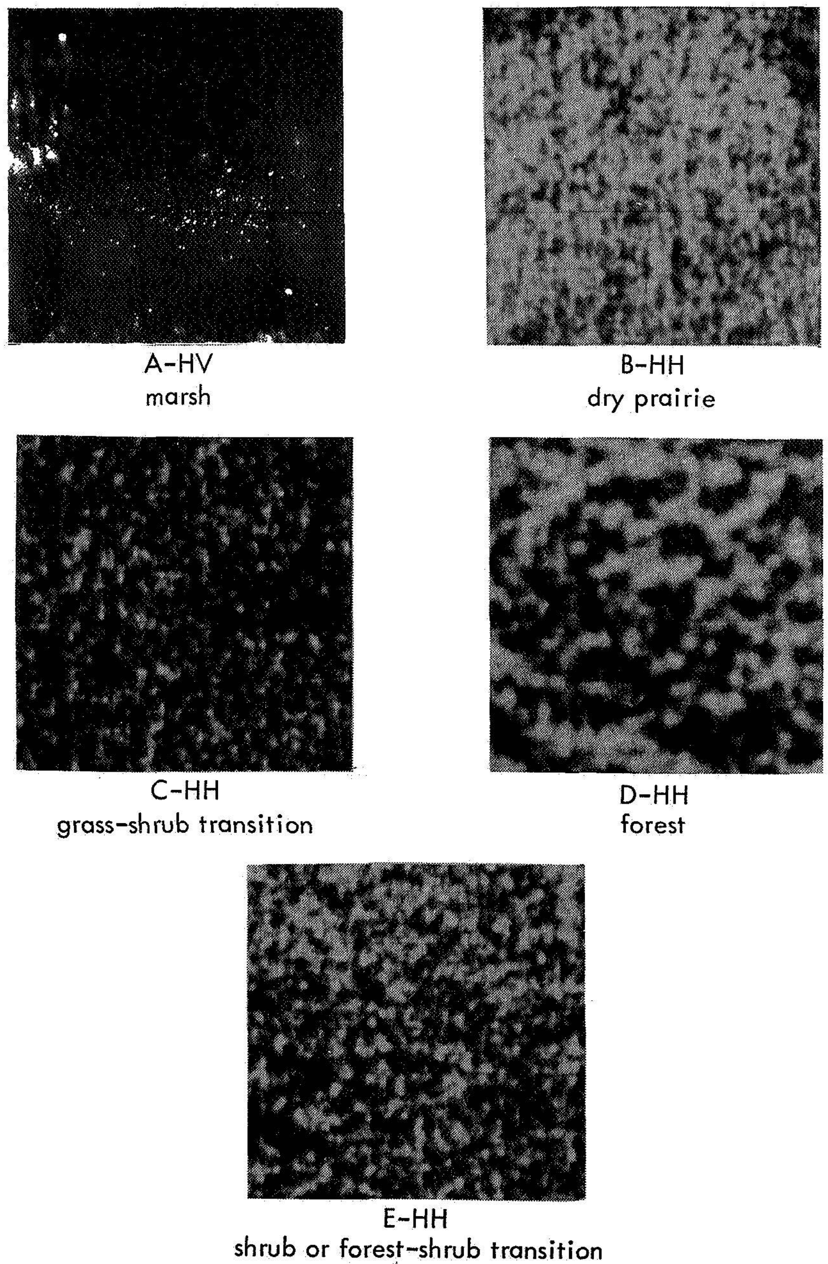
The texture for well developed forest may be compared to that for a probable young forest of forest-shrub transition (E). This type has a similar but finer image texture possibly arising from shorter trees. The noticeable decrease in the proportion of no or little return areas indicates a decrease of radar shadowing, while the increase in medium return energy may result from a higher proportion of the signal reaching ground level.

Image texture patterns for non-forest types (A, B, C) are notably finer in texture and much more uniform in gray scale value (i.e. the variance around the mean value is less than for the forest types). Height ceases to be a significant parameter in natural grass or shrub lands resulting in reduced contrast and an increase in the number of pulse lengths on the ground giving nearly the same energy return.

As an example of possible future capabilities using a flying spot scanner coupled to a pulse height analyzer in studying forest environments, figure 10 illustrates probability density curves for selected areas on the Oregon imagery corresponding to the image textures in fig. 9. Five areas were selected for comparison which range in type from marsh to forest passing through major transition types. Both the HH and HV images were utilized and each area had a ground dimension of 1 km by .75 km. Care was exercised to maintain area homogeneity but forested areas in general present problems of radar shadowing because they are usually associated with more dissected and rugged topography.

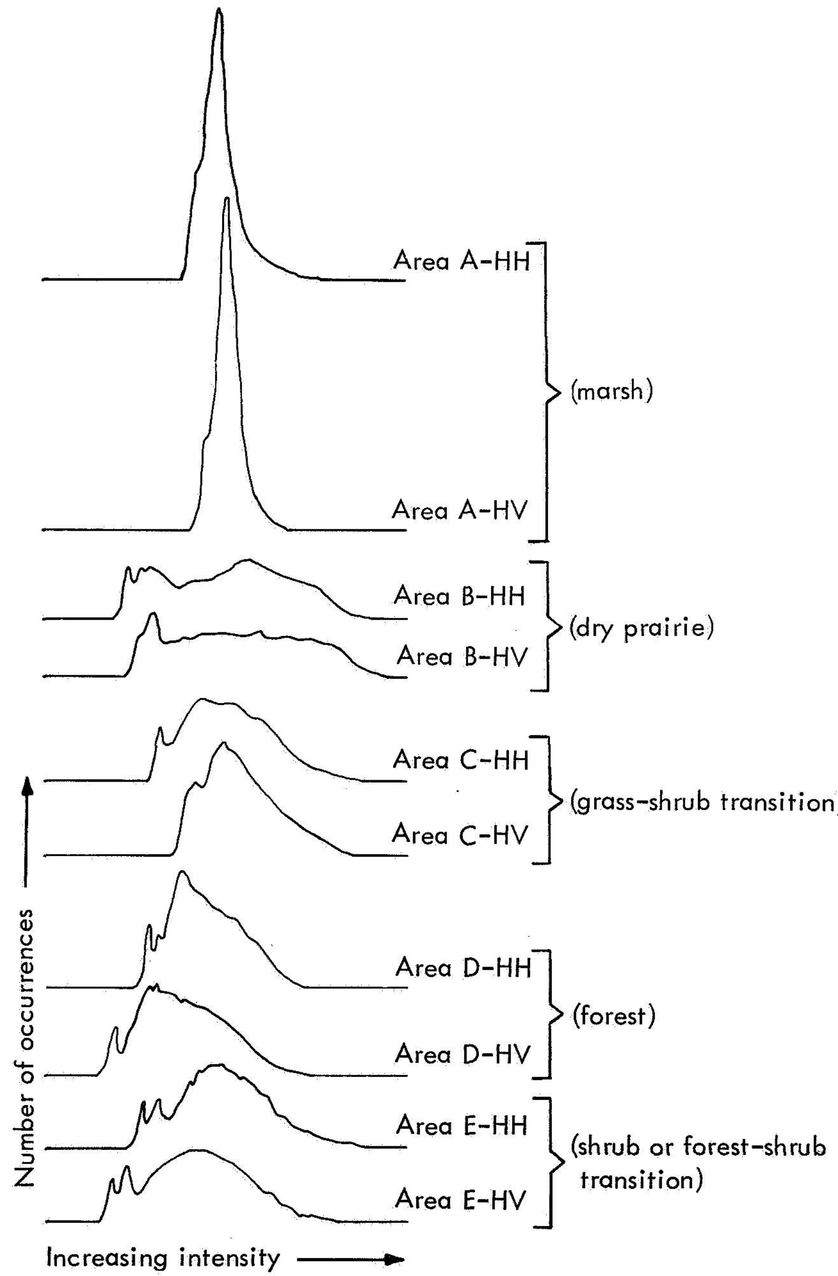
As with the probability density curves presented for Escalante Valley, it is not yet appropriate to assess the meaning of individual peaks and nulls for each of the Oregon curves. A few general points should be noted, however. Area B is composed primarily of medium to high intensity returns from what is reported to be dry prairie on the topographic map (fig. 7). If this high intensity is portrayed on the probability density curve by the rather broad and low peak in the high intensity portion of the curve, which seems reasonable, then the secondary peak observable in the lower intensity region may be correlated with low return marsh channels interfingering with the prairie. While these comments are speculative at present, they indicate some of the potential rewards for continuing this method of analysis. In the initial stages of creating a catalog of vegetation curves, however, it would be desirable to minimize complexities arising from scanning more than one terrain phenomenon for a given area.

Perhaps one of the more interesting features about the probability density curves lies in comparing those for Escalante Valley and south-central Oregon. Here may be noted some degree of similarity between the general shape of curves for such types as Oregon marsh and Utah



K-Band Enlargements of image texture patterns for some forest and non-forest areas in south-central Oregon

Figure 9



Probability density curves for representative vegetation types (film densities) in south central Oregon

Figure 10

shadscale. Comparisons of this kind for all the curves presented illustrates the potential importance of secondary peaks and minor variations in the shapes of curves, since, despite their similarity, they contain notable and perhaps diagnostic differences of the sort which may be necessary to perform "type" separations.

5.3 YUKON FLATS, ALASKA

As a last example of the potential value of radar imagery for studying vegetation patterns, a portion of Yukon Flats, Alaska is illustrated. Imagery for this area (fig. 11) was obtained in October, 1957, through dense stratiform undercast by an AN/APQ-56 Ka band (8.6 mm) system having a resolution of about 30 meters and an image ground scale of about 1:350,000. Unlike imagery previously illustrated however, only one polarization was transmitted and received.

The tentative vegetation map (fig. 12) has not been field checked, but Dr. Philip Johnson of the U.S. Army Cold Regions Research and Engineering Laboratories has confirmed the major points of the interpretation from his experience in that part of Alaska. The interpretation incorporates criticisms by Dr. Johnson of an earlier map prepared by us of this area. The physical setting of this area has already been discussed in more detail elsewhere (Simonett and Morain, 1965).

On the negative imagery areas of low energy appear in part to represent a previous fire pattern as evidenced by an east-west lenticular interfingering of film densities and their associated sawtooth edges. This interpretation is strengthened by the reported occurrence in 1940 of the Box Car Burn, which swept westward through this area from the Porcupine River to the Christian River burning some 192,000 acres (Lutz, 1956). The evident north-south belted arrangement of film densities further suggests an occurrence of vegetation zones paralleling major drainage lines and upon which the burn pattern of 1940 may have been superimposed. Vegetation successional stages are not fully known for Arctic Alaska, but it is likely that willow, aspen, and some white birch are actively invading these burned areas.

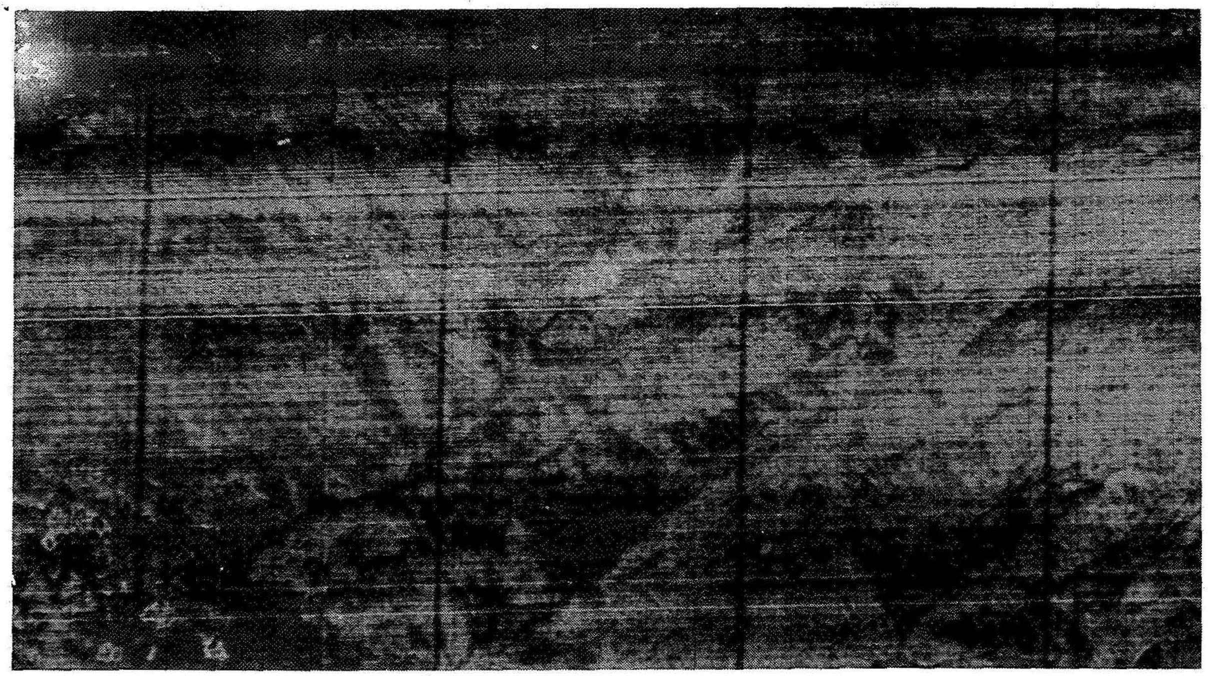
Areas of high return (dark gray) have been interpreted as white spruce (Picea glauca). This species tends to form relatively dense and near monospecific stands in moist environments along narrow flood plains and lake margins, but may also exist as islands in fire burn. Regions of intermediate energy (medium gray) probably correspond to open, dwarf forest of black spruce (Picea mariana) and white birch (Betula papyrifera) with an understory of ericaceous shrubs and mosses (Johnson, personal communication).

The AN/APQ-56 imagery is poor in system performance in comparison to that produced by more recent systems. Image texture patterns are altogether absent in this study area, and film density patterns are not well defined. Similar film density patterns have been observed in other areas on this imagery, and, in fact, some of the dense galeria forests north of Yukon Flats begin to appear as distinct image texture differences even on this dated imagery.

Probability density functions were not prepared for the AN/APQ-56 imagery because of marked side-lobing which seriously degrades this imagery. Furthermore the rationale for correcting variations between radar systems themselves has not been outlined. Until this is done, there can be no meaningful comparison of probability density curves from different systems.

6. SUMMARY

The three regions discussed exemplify a very small range of vegetation types and conditions, but we hope the results of this discussion are sufficiently convincing to stimulate continued studies of vegetation with radar imagery. The information content obtained from long wavelength, active sensors could serve as a useful corollary to information obtained from the visible, near IR, and thermal IR regions because energy returns beyond the millimeter wavelength range are greatly influenced by factors of physiognomy. Escalante Valley, Horsefly Mountain, and Yukon Flats begin to shed light on our understanding of some of these factors, but no doubt there are others of equal importance to be gleaned from yet unstudied environments. The ever growing body of radar theory provides us with the basic where-with-all to begin relevant quantitative assessment of geometric parameters. The theory is now beginning to be supplemented with appropriate field data collected for the radar interpreter. The next step is to develop field and laboratory experiments designed to evaluate specific parameters. A number of field experiments are underway in western Kansas on agricultural fields as a joint project of the University of Kansas and Kansas State University Agricultural Experiment Station; and at Purdue University as a joint project of the Botany and Agriculture departments and the Ohio State University Antenna Laboratory. No experiments have yet been run on natural vegetation types. The results given in this paper clearly suggest that radar experiments should be made on many natural vegetation types.



AN/APQ-56 Radar negative imagery for a portion of Yukon Flats, Alaska

Figure 11

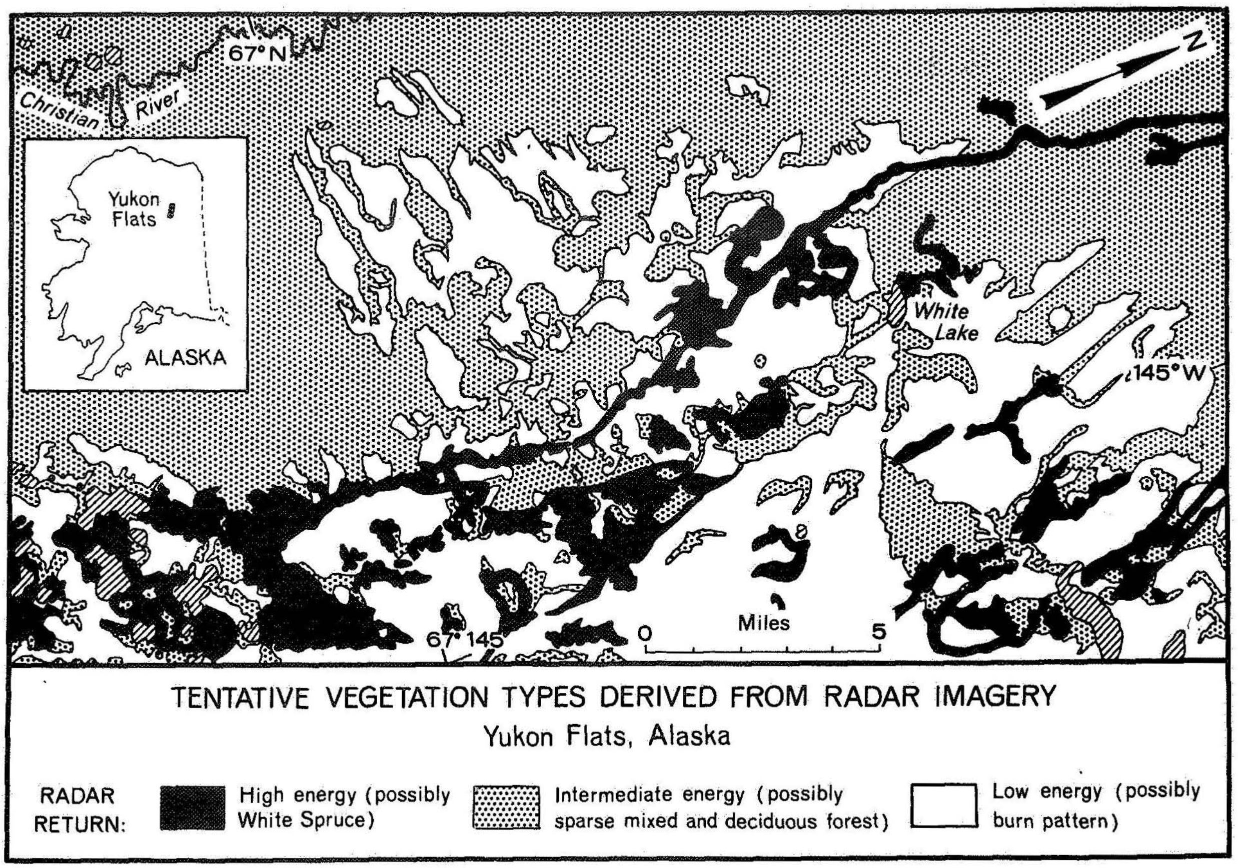


Figure 12 Tentative vegetation types of Yukon Flats, Alaska (after Simonett and Morain, 1965)

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